Dark Current Reduction of Avalanche Photodiode using Asymmetric InGaAsP/InAlAs Superlattice Structure

Asamira Suzuki, Atsushi Yamada, Tatsuo Yokotsuka, Ken Idota and Yoshimasa Ohki

Advanced Technology Research Laboratories, Matsushita Electric Industrial Co., Ltd.

3-10-1, Higashi-mita, Tama-ku, Kawasaki, Kanagawa 214-8501 Japan

E-mail address: kikkawa@mrit.mei.co.jp

We apply asymmetric superlattice (SL) structure to avalanche photodiode (APD) to improve its dark current to make low. We produce the asymmetric SL-APD with varying the parameters that are thickness of barrier and well layers that change effective band gap ($E_{g\ eff}$) under the total thickness of SL keep constant. Then we evaluate static characteristics by I-V and C-V measurements. InGaAsP/InAlAs SL-APD has advantage on low excess noise due to small valence band discontinuity between InGaAsP and InAlAs. Because this valence band discontinuity disappearance and large conduction band discontinuity brings about small k= / which is the ratio of the electron ionization rate to the hole ionization rate . As a result of asymmetric SL multiplication layer structure, dark current property was improved maintaining its excellent low excess noise property.

We grow the SL-APD structures by gas-source MBE on S-doped n-InP (001) substrate. Group III sources and the dopants (Si, Be) are solid material and group V sources are gaseous (PH_3, AsH_3) using a high-temperature cracking cell. Basically growth temperature is at 470 in order to avoid the reevaporation of phosphorous except SL layers that contain Aluminum are grown at 500 . The combination of well and barrier layer thickness is shown in table 1.

Figure 1 shows the schematic view of SL-APD. Mesa diameter of the APD device is 40 μm. The capacitance is as small as 120fF at working bias voltage where the absorption layer is thoroughly depleted. Characteristics of dark and photo current on sample C versus to inverse bias are shown in figure 2. At whole bias voltage region, the dark current of sample C is lowest among the three samples in table 1. This improvement (low dark current) is due to relative large $E_{g\ eff}$ that depend on the well and barrier thickness. Figure 3 shows that the dark current values versus multiplication factor (M). Small ratio of thickness between InGaAsP and InAlAs introduce the larger $E_{g\ eff}$ and cause the lower dark current at typical working region. The dark current value of sample C at M=10 is 0.4μ A.

In conclusion, to optimize combination of the well and barrier thickness in the asymmetric SL, we can reduce the dark current of SL-APD at the working region. It is the excellent candidate for optical receiver of long distance optical communication system.

Table 1. Parameters of the SL multiplication layer structures.

Sample	Barrier layer thickness [nm]	Well layer thickness [nm]	Periods	Total thickness of SL multiplication layer [nm]
A	11.5	11.5	13	299.0
B	13.0	10.0	13	299.0
C	16.0	7.0	13	299.0
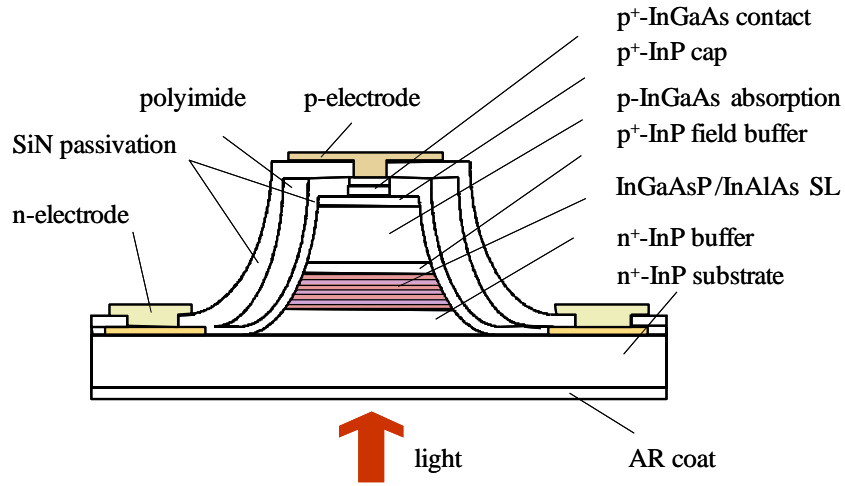
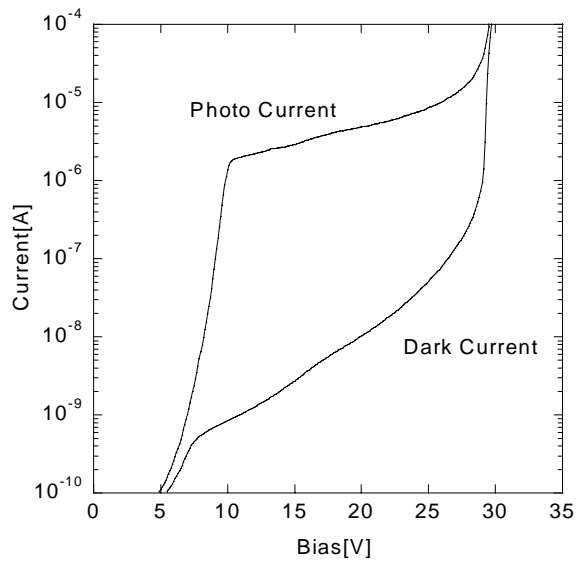Fig. 1. Schematic device structure of InGaAsP/InAlAs SL- APD.

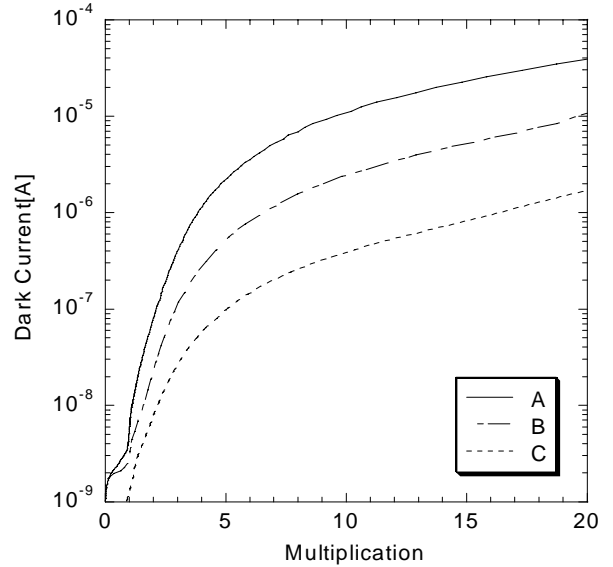Fig. 2. Photo current and dark current characteristics of sample C.

Fig.3. Relationship between the photocurrent multiplication factor and the dark current.